

The variable ROSAT X-ray spectrum of the BL Lac 0716+714

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February 1, 2008

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Monthly Notices of the Royal Astronomical Society: in press

Abstract

The BL Lac object 0716+714 is a powerful flat spectrum radio source detected by CGRO-EGRET at γ -ray energies. It has been observed for about 21000 s over two days by the X-ray telescope onboard the ROSAT satellite and strong flux and spectral variations have been detected. In the time scale of two days the source varied by a factor of ~ 7 ; during a sudden (~ 1000 s) flux increase, the variation was 70%. Spectral analysis was performed first using the model independent hardness ratio technique and then the data were fitted using several standard spectral shapes. Both analysis agree on the conclusion that 0716+714 exhibits spectral variations related to source flux variability which may be attributed to a “soft excess” component most prominent when the source was in a low state. The spectrum of 0716+714 steepened in the soft X-ray band when the flux decreased while in the hard X-ray band remained constant. A double power law model, representing steep synchrotron radiation at low energies and flat inverse Compton radiation above ~ 1 keV, best fits both the low and high state.

Key-words: Active Galactic Nuclei - Blazars - X-rays: spectroscopy - Synchrotron Self Compton

1 INTRODUCTION

BL Lac objects are a class of Active Galactic Nuclei (AGNs) characterized by weak or absent emission lines, a polarized optical and radio continuum and dramatic variability at all wavelengths. With High Polarization Quasars (HPQs) and Optically Violently Variable Quasars (OVVs) which display rather similar continuum properties, they form a class of objects collectively known as blazars. There is now a general agreement that for blazars the radio-to-optical continuum is emitted by high energy electrons via synchrotron radiation (Bregman 1990). This emission mechanism may occur in a relativistic jet closely aligned with the observer's line of sight. The radiation we observe, therefore, may be highly enhanced since it is beamed along the jet's axis (Königl 1981). The origin of the high energy continuum in BL Lac objects, on the other hand, is not yet clear. It has been suggested that two components due to synchrotron and Compton radiation mechanisms may be present in the X-ray band. While the former should smoothly connect to the low frequency portion of the spectrum which, because of radiative losses, should steepen with increasing frequency, the latter should cause flattening in the X-ray band with respect to lower frequencies (see Maraschi, Maccacaro & Ulrich (1989) for a summary of the field).

Observations of X-ray selected BL Lac objects by the Einstein Observatory (Schwartz & Madejski 1989), EXOSAT and GINGA have shown that their spectra are steep and convex, suggestive of a synchrotron origin (Barr et al. 1989). Classical radio selected BL Lacs, on the other hand, tend to have flatter, and in some cases concave, X-ray spectra suggestive of a Compton radiation component (Kii et al. 1991). Blazars in general have been clearly detected at γ -ray energies by the EGRET instrument on the Compton Gamma Ray Observatory (CGRO, Thompson et al. 1993). These detections have been interpreted as the extension of the Compton component to MeV energies and, in the case of MKN 421, to TeV energies (Punch et al. 1993). On average spectra of BL Lac objects observed by ROSAT (Fink et al. 1992) have steeper slopes than those measured by the Einstein Observatory at slightly higher energies (Worrall & Wilkes 1990, Perlman et al. 1994).

It should be noted that X-ray observations of bright BL Lac objects with high resolution instruments have sometimes revealed an absorption feature at $E \sim 0.6 \div 0.7$ keV and $\Delta E \sim 100$ eV presumably due to O VIII Ly α resonant absorption (Canizares & Kruper 1984, Madejski et al. 1991). The presence of such spectral feature, if not explicitly fitted, could substantially modify the

observed spectrum in a low resolution detector like the ROSAT PSPC.

Although it is known that BL Lac spectra do vary with time (Giommi et al. 1990), it is not at all understood whether the spectral variations are associated to the observed flux variations. To test the validity of some model predictions, multifrequency studies have become common practice. Simultaneous observations of the same object at many different frequencies allow to explore different regions and examine the physical processes at work. The analysis of temporal and spectral variabilities are, however, not always simple and the interpretation of the results is not straightforward. It must be emphasized, however, that observations as the ones discussed here provide a powerful probe of the temporal and spectral behaviour of a well defined physical region in the proximity of the central engine.

In this paper the full analysis of a ROSAT observation of the BL Lac object 0716+714 is reported. This observation is of particular interest since spectral and temporal variability could be studied on rather long time scales, as the ROSAT pointings were distributed over two days, as well as on short time scales since the source experienced at least one outburst lasting about 1000 s during the observing period.

The paper is organized as follows: general information on 0716+714 are given in section 2 while the ROSAT observation is described in section 3. Subsection 3.2 describes the temporal analysis and 3.3 the hardness ratio analysis. The spectral analysis is presented in subsection 3.4. A discussion of the results is presented in section 4 and the conclusions are summarized in section 5.

Throughout the paper a Hubble constant $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and a deceleration parameter $q_0 = 0$ are assumed.

2 Data on BL Lac 0716+714

The BL Lac object 0716+714 (RA: $07^h 21^m 53.4^s$, Dec: $71^d 20^m 36^s$ at epoch 2000) is one of the BL Lacs best studied over the entire electromagnetic spectrum. It was discovered as the optical counterpart of one of the 1 Jy radio sources catalogued by Kühr et al. (1981) and belongs to the complete sample of 1 Jy radio-selected BL Lacs (Stickel et al. 1991).

In the radio band the overall spectrum is flat, with a spectral index $\alpha_r = -0.22$ between 11 and 6 cm ($S_\nu \propto \nu^{-\alpha}$), and progressively steepens at higher energies (Impey & Neugebauer 1988).

In the optical band 0716+714 is the brightest object of the 1 Jy catalogue of

BL Lacs with $m_v = 13.2$ (Stickel et al. 1993) and is one of the five objects in the sample which shows neither emission nor absorption features in the spectrum even after long integration times. A magnitude $m_v = 15.5$, corresponding to a decrease of $\Delta m_v = 2.3$ between August 1979 and January 1980, has also been reported (Biermann et al. 1981). A lower limit on the redshift ($z > 0.3$) has been derived from the non-detection of the host galaxy (Wagner 1992).

Intensive monitoring campaigns carried out simultaneously in the radio and optical bands (Wagner 1992) show strong and correlated variability occurring on time scales of less than one day.

0716+714 is one of the five BL Lac objects detected by the EGRET detector onboard CGRO at energies above 100 MeV. Large flux and spectral variations have been detected at these wavelengths (Kurfess 1994).

The only previous X-ray measurement of 0716+714 in the X-ray band has been carried out with the Einstein Observatory IPC in the 0.2 – 3.5 keV energy range (Biermann et al. 1981). The source however was too weak to allow a detailed spectral and/or temporal analysis.

3 Data Analysis

3.1 Data acquisition and reduction

The BL Lac object 0716+714 was observed on-axis with the PSPC detector (Pfeffermann et al. 1986) onboard the ROSAT Observatory (Trümper 1983) for a total of about 21000 s between the 8th and 11th of March 1991. The analysis which follows is based on the data accumulated during this observation obtained from the ROSAT public data archive. The ROSAT telescope was pointed at the source 14 different times but one pointing was so short that no photons were detected. Source photons were collected from a circle of 2 arcmin radius centered on the object position and background counts were collected from a ~ 10 times larger area in a ring surrounding the source. The total source photons accumulated during the pointing was about 16300. The data were corrected for the vignetting and deadtime of the telescope and the mean corrected count-rate in the energy range $\sim 0.1 - 2.4$ keV was 0.802 ± 0.006 counts s⁻¹. Data preparation and analysis have been performed using the JAN94 version of the EXSAS package (Zimmermann et al. 1993); spectral analysis has been performed using version 8.33 of the XSPEC program (Arnaud et al. 1991).

3.2 Temporal analysis

As a first step, all photons collected by ROSAT were binned in 400 s time intervals as suggested by the wobble period of the telescope and the resulting light curve is shown in Fig. 1, panel a. The X-ray count-rate decreases with time from a high level of ~ 1.8 cts/s to a low level of ~ 0.3 cts/s two days later. During the whole ROSAT observation, the ratio of maximum to minimum count rate is ~ 7 . In the second observation interval (5000-6000 s), an increase in the count rate of about 70% in less than 1000 s is present. This sudden burst of radiation, hereafter called “flare”, has been previously noted by Witzel et al. (1993). Panel b of Fig. 1 shows the increasing count rate during the flare; the decay of this event was not monitored. In a time span of 7000 s the source count rate decreased by a factor 2 (Fig. 1, panel c). As the count rate decreases with time the X-ray continue to flicker but on longer time scales.

3.3 Hardness ratio analysis

Due to the high variability of this BL Lac, the first step in analyzing the data has been to investigate variations in hardness ratio. This provides a powerful tool for the detection of X-ray spectral variability as the hardness ratio is model-independent.

The hardness ratio $HR = \frac{(H-S)}{(H+S)}$ was computed using the EXSAS standard energy intervals: $S(\sim 0.1 - 0.4 \text{ keV}) = \text{net counts between channels } (11 \div 41)$ and $H(\sim 0.5 - 2.0 \text{ keV}) = \text{net counts between channels } (52 \div 201)$.

The full observation was subsequently divided in 4 different time periods and precisely the pre-flare (very high and constant count rate), the flare (very high and increasing count rate), the post-flare (high and decreasing count rate) and the low period (low count rate). Time selections, accumulated counts and mean count-rates for each period are reported in Table 1.

The HR lightcurve (Fig. 2, panel a) clearly shows that the first two intervals have harder HR than the last two. A χ^2 -test of the HR light curve against constancy leads to a $\chi^2_{red} \simeq 39.7$ for 3 *d.o.f.* corresponding to a probability $p \simeq 10^{-8}$.

Given the high number of counts accumulated during the flare and post-flare periods and the rapid flux variation seen, each interval was further inspected for HR variability; the results obtained are consistent with HR being constant within the statistical errors.

From Fig. 2 panel a, two general states can be identified, each with a constant hardness ratio: a high (and hard) state at the beginning of the observation, including the pre-flare and the flare periods (see Table 1) with $\langle HR \rangle = -0.01 \pm 0.02$, and a low (and soft) state for the rest of the observation, including the post-flare and the low period (see Table 1) with $\langle HR \rangle = -0.12 \pm 0.01$.

In order to further investigate the spectral behaviour within the high and the low state, a more detailed hardness ratio analysis has been performed. For both states the data were binned in 4 energy ranges: the soft band S1 (channels $11 \div 41$), the medium band S2 (channels $50 \div 89$), the hard band H1 (channels $90 \div 139$) and the very hard band H2 (channels $140 \div 200$) (cf. Molendi & Maccacaro 1994). Two new hardness ratios defined as $HR_{soft} = \frac{(S2-S1)}{(S2+S1)}$, $HR_{hard} = \frac{(H2-H1)}{(H2+H1)}$ have then been computed.

The resulting hardness ratio light curves (Fig. 2, panels b and c) show that the HR_{soft} decreases with decreasing intensity whereas the HR_{hard} remains constant. χ^2 -tests against constancy give probabilities of $\sim 2 \cdot 10^{-5}$ and ~ 0.66 respectively. In order to check whether the non-detected variation of HR_{hard} were related to lower statistics, the statistical errors associated to HR_{hard} were assigned to HR_{soft} and the resulting HR_{soft} values tested against constancy; again a decrease of HR_{soft} was detected at a confidence level $> 3\sigma$.

The results from the hardness ratio analysis can be summarized as follow:

- 1) The high state is harder than the low state at a confidence level $>> 99\%$. This is evidence for spectral variability associated with amplitude variability, more specifically the source spectrum steepens with decreasing intensity.
- 2) The steepening is clearly observed below ~ 0.9 keV, while the spectrum remains constant at harder energies, suggesting the presence of two distinct spectral components over the broad energy band ($\sim 0.1 - 2.0$ keV).

3.4 Spectral analysis

To quantify the model independent but qualitative results obtained from the HR analysis, spectral analysis for the high state and the low state (as defined in the previous section) was performed. The spectra discussed in the following paragraphs were obtained from the pulse height spectra binned so that the signal to noise ratio would remain ≥ 10 in each channel; the resulting degrees of freedom are, therefore, different for different states. The ROSAT data reduction staff (ROSAT news letter n.20, August 1993) recommended the use of the old matrix for AO-1 observations such as the present one; to comply with these instructions

the DRM06 detector response matrix was used in the present analysis.

3.4.1 Single power law fits

A single power law model with low energy absorption has been fitted to both states with free N_H . The best-fit parameters are given in Table 2 and the χ^2 confidence contours in the parameter space $N_H - \Gamma$ are shown in Fig. 3. It is evident that the hydrogen column density derived in the low state is not consistent at a confidence level $\gg 99\%$ with the galactic value derived from radio maps $N_{Hgal} = 3.95 \cdot 10^{20} \text{cm}^{-2}$ with an associated error of the order of 10%, see Dickey & Lockman (1990). On the contrary, the high state is reasonably well described by a single power law with Galactic absorption.

To test the possibility that the difference in χ^2_{red} for the low and high state may be related to the difference in total counts accumulated, only a part of the low state (the low period, with a total number of counts ~ 6900 which can be compared with the high state statistics) was fitted with a power law model and Galactic absorption.

A rather poor fit with $\chi^2_{red} \simeq 2.2$ for 50 *d.o.f.* was obtained which corresponds to a probability $p \simeq 4 \cdot 10^{-6}$. The resulting confidence contours are also shown in Fig. 3 and compared with the results obtained for the low and high states. A fit of the post-flare period yielded similar results i.e. $\chi^2_{red} \simeq 1.6$ for 42 *d.o.f.*, corresponding to $p \simeq 8 \cdot 10^{-3}$. These results confirm that even with lower statistics, the low state is not consistent with a single power law with Galactic absorption.

This spectral analysis confirms the two previous results obtained with the hardness ratio analysis:

- 1) There is evidence for a spectral variation in 0716+714 related to the source variability.
- 2) These variations can be attributed to the presence of a second spectral component, a “soft excess”, which is prominent only when the source is in the low state.

3.4.2 Two-components models

The pulse height spectrum of the low state was fitted with the following two-component models: bremsstrahlung + power law, double power law and power law + absorption trough. N_H , when left free to vary, turned out to have a value close to the Galactic value, therefore it has been fixed at the Galactic value in all models.

These three spectral models can be related to three different astrophysical scenarios. In the first model (thermal bremsstrahlung + power law), the soft thermal component is assumed to be related to emission from the host galaxy while the hard power law component should be related to its nucleus. It could be argued that if the galaxy hosting the BL Lac were an elliptical galaxy, a more realistic model would be to fit a Raymond-Smith type of spectrum. This fit was also attempted and the results turned out to be very similar to the one obtained fitting a thermal bremsstrahlung spectrum. However, as discussed later on, both models will have to be discarded on the basis of luminosity considerations. One should also point out that the soft portion of the spectrum can be fitted by a black-body spectrum as well which, however, was disregarded as of no physical meaning. This is to say that with the present data the soft excess can set very weak constraints on models.

In the second model (double power law), the steep power law dominating at soft energies and the hard power law can be related respectively to synchrotron and inverse Compton processes.

In the third model (power law + absorption trough), the observed spectral shape is explained as a single power law component undergoing absorption by material present within the nucleus.

With all the parameters free to vary, all three models yielded acceptable fits to the source spectrum in the low state. The χ^2_{red} values are respectively 0.78, 0.79 and 1.20 for 75 d.o.f. as reported in table 3 (“low state”). As an example the double power law model fit to the data is shown in Fig. 4. Thus the present data do not allow to discriminate directly between the 3 proposed models.

For the high state fit as many parameters as possible were fixed at the value found for the low state. The aim of this approach is to select the model which could describe the source spectrum both in the low and the high states varying the least number of parameters.

The results obtained with the 3 different models are summarized in table 3 (“high state”). It should be pointed out that the hardness ratio analysis was described “going” from the high state to the low state while, for reasons of consistency with the above mentioned approach, the results of the spectral analysis are described “going” from the low state to the high state.

Moreover the following considerations seem in order:

a) The bremsstrahlung + power law model apparently is the model that best fits the data. In fact it describes both states by only “shifting” up or down

the power law normalization. The spectral analysis shows that the pulse height spectrum can be described in both low and high states with the sum of a constant plus thermal emission and a variable power law which dominates at $E \gtrsim 1$ keV. The thermal bremsstrahlung has a characteristic temperature ~ 76 eV and a constant flux $F_X(0.1 - 2.4) \simeq 7.3 \cdot 10^{-13}$ ergs cm $^{-2}$ s $^{-1}$. The power law has a fixed steep spectrum with $\Gamma \simeq 2.7$ but varies its intensity by a factor of about 3. In the context of this model, the spectral hardening with increasing flux observed in the soft band (see section 3.4.1) can be understood in terms of a larger contribution from the power law component, e.g. the hard component, in the soft band with respect to its flux increase.

b) The double power law model failed to describe both states when only one normalization was varied ($\chi^2_{red}/d.o.f \geq 7.4/33$). This model requires the variation of at least 2 parameters in order to explain the measured intensity and spectral variations. Of the six possible choices with two free-parameters, only 3 yielded an acceptable fit for the high state and precisely the ones with Γ_{hard} and A_{hard} free, Γ_{soft} and A_{soft} free or A_{soft} and A_{hard} free (see table 3), where Γ is the photon index and A is the power law normalization.

The first solution is consistent with a variation in shape and intensity of the hard component while the soft component is fixed. This case requires an increase by a factor of $3 \div 4$ of the hard power law intensity and a steepening of its photon index from 2.25 to 2.72.

The second solution requires a spectral hardening with increasing flux of the soft component while the hard component remains constant. In this case, the soft component increases by a factor of about 10 and shows a hardening (Γ_{soft} going from 3.99 to 3.12). The soft component becomes the dominant component for the whole broad energy band while the hard component remains constant.

The third solution requires a flux variation of both components but with this model, both components are constant in shape. From the best fit values, we have obtained $\frac{A_{soft}(high\ state)}{A_{soft}(low\ state)} \sim 2$ and $\frac{A_{hard}(high\ state)}{A_{hard}(low\ state)} \sim 3$. These ratios show that the hard component increased more than the soft component but both variations are of the same order of magnitude.

All three possible double power law solutions described above can explain the hardening in the soft band as measured with the hardness ratio analysis (see section 3.3).

c) The power law + absorption trough model failed to describe both the low and the high states by only varying the covering factor, giving $\chi^2_{red}/d.o.f. \simeq 44/33$

for the best-fit of the high state. Therefore the observed intensity and spectral variations cannot be explained simply varying the absorption trough. With two free-parameters, namely the power law normalization and the photon index, the model provides acceptable fits for both low and high state. However, one should note that in this case the variations are intrinsic and not related to the absorbing medium, and consequently of little physical interest.

The results of the spectral analysis of BL Lac 0716+714 can be summarized as follows:

1) There is a strong evidence for the presence of a second spectral component in the energy band $\sim 0.1 - 2.4$ keV (section 3.4.1), at least for the low state. This confirms the conclusions reached with the hardness ratio analysis.

2) The three different models used yield acceptable fits for the low state spectrum and therefore, given the PSPC resolution, no preferential model can be chosen.

3) The attempt to describe both states with the same model allows to discard the power law + absorption trough model.

In order to preserve a logical sequence of arguments the bremsstrahlung + power law and the double power law models will be discussed in section 4.2 below.

4 Discussion

4.1 Time Variability

For 0716+714 the shortest doubling time-scale detected in the soft X-ray band is around 7000 s and occurred during the post-flare period (see Table 1 for definition). During this time interval, the $0.1 - 2.4$ keV flux decreased by $\sim 3.7 \cdot 10^{-11}$ ergs $\text{cm}^{-2} \text{s}^{-1}$, indicating a luminosity variation $\Delta L_x \gtrsim 1.9 \cdot 10^{46}$ ergs s^{-1} (assuming $z \gtrsim 0.3$ and the double power law spectrum). Assuming that the luminosity is produced by matter being transformed into radiation with some efficiency η ($\eta = \frac{L \cdot t_{var}}{M \cdot c^2}$), the net result for a spherical source is

$$\Delta L \leq \eta \frac{m_p c^4}{\sigma_T} t_{var} \quad (1)$$

where σ_T is the Thomson cross section and m_p the mass of the proton (Fabian 1992).

The observed luminosity variation $\Delta L_x \sim L_x \sim 1.9 \cdot 10^{46}$ ergs s⁻¹ at $z = 0.3$ with $t_{var} \sim 7000/(1+z)$ s implies $\eta > 1$, and therefore strongly suggests that the observed X-ray radiation is beamed.

Independent evidence of relativistic motion in this source is derived from the observed superluminal velocity of radio knots ($\beta_{app} = 4.6$, Ghisellini et al. 1993). The same authors have estimated a Doppler factor, in the framework of the Synchrotron Self-Compton (SSC) model, of $\delta \geq 2.1$.

A lower limit on the γ -ray luminosity has been computed from the observed EGRET fluxes and spectral slopes (Kurfess 1994). In the 0.1 – 5 GeV energy interval the observed luminosity is in the range $L_\gamma \simeq 7.4 \cdot 10^{46} \div 1.2 \cdot 10^{47}$ ergs s⁻¹ (with $z=0.3$). The fact that the γ -ray luminosity dominates the total radiated power implies that 0716+714 must be transparent to photon-photon interaction. The optical depth ($\tau_{\gamma\gamma}$) for this process is

$$\tau_{\gamma\gamma}(x) = f(\alpha) \frac{l(1/x)}{4\pi} \quad (2)$$

where the compactness l is defined as $l(x) = L(x)\sigma_T/Rm_e c^3$, x is the photon energy ($x \equiv \frac{h\nu}{m_e c^2}$), α is the energy spectral index of the target X-ray photons in the γ -ray emitting region and $f(\alpha)$ is a numerical factor taken from Svensson (1987). In this process, a photon with energy x preferably interacts with photons of energy $1/x$.

Assuming that γ -rays and X-rays are produced in the same region, and imposing the condition of transparency for the photon-photon interaction ($\tau_{\gamma\gamma} < 1$), it is possible to compute the Doppler factor. Estimating the intrinsic source size from $R = ct_{var}\delta$, one has $\tau_{\gamma\gamma}(x) \propto \delta^{-4} L_{obs}(\delta^2/x)$ where L_{obs} is the luminosity in the observer rest frame. Assuming $L(\nu_0) \propto \nu_0^{-\alpha}$, the limit on the source compactness (i.e. $\tau_{\gamma\gamma} < 1$) gives a limit to the value of the Doppler factor:

$$\delta > \left[\frac{f(\alpha)\sigma_T}{4\pi c^2 t_{var}} \frac{\nu_0 L(\nu_0)}{h\nu_0} \right]^{1/(4+2\alpha)} \quad (3)$$

where α , ν_0 and $L(\nu_0)$ are the energy index, the frequency and the monochromatic luminosity of the X-ray target photons. This formula, originally derived in Ghisellini (1993), has been applied, in a somewhat different form, to 3C279 by Maraschi, Ghisellini & Celotti (1992). From the observed doubling time scale and luminosity at 1 keV ($L_x \simeq 1.3 \cdot 10^{45}$ ergs s⁻¹ keV⁻¹), and with $\alpha = 1$ (leading to $f(1) \simeq 0.12$), the limit of $\delta \gtrsim 3.2$ and $R \gtrsim 5.2 \cdot 10^{14}$ cm for the X and γ -ray emitting region are obtained. One should bear in mind that the above values

where obtained adopting a lower limit for the X-ray luminosity estimate due to the conservative value ($z = 0.3$) for the redshift.

With the above values for the Doppler factor and the superluminal motion $\beta_{app} \simeq 4.6$ an upper limit for the Lorentz factor for the bulk motion $\Gamma \lesssim 5.1$ and for the angle to the line of sight $\phi \lesssim 17$ degrees were obtained.

4.2 Spectral constraints

The hardness ratio and spectral analysis strongly suggest that the soft X-ray spectrum of 0716+714 consists of two distinct components. In section 3.4.2 we have compared the data to various trial models. The possibility that spectral and intensity variations are related to variations of an absorption trough has been shown to be inconsistent with the data.

The thermal component + power law model can satisfactorily fit the low and high state of the source by varying only the power law normalization. It would therefore appear that the PSPC spectrum of 0716+714 can be explained as the sum of a soft constant thermal component, related to the host galaxy, plus a variable non-thermal component associated to the BL Lac.

The calculation of the lower limit (assuming $z = 0.3$) of the luminosity for the thermal component leads to a value of $L_x(0.1 - 2.4 \text{ keV}) \simeq 4 \cdot 10^{44} \text{ ergs s}^{-1}$. This is more than two orders of magnitude larger than the highest luminosity observed for elliptical galaxies (Fabbiano et al. 1992). This model must, therefore, be abandoned as a plausible explanation for the data.

The only acceptable explanation for the X-ray spectrum is in terms of a double power law model. In this context the steep power law dominating at soft energies can be related to the synchrotron emission while the flat power law emerging above $\sim 1 \text{ keV}$ is due to inverse Compton emission. The limited spectral resolution of the PSPC does not allow to distinguish between different explanations for the observed spectral variability. More specifically the low and the high state can be satisfactorily fitted by varying: 1) the spectral index and normalization of the soft component, 2) the spectral index and normalization of the hard component, 3) the normalization of the soft and hard component. All 3 possibilities are consistent with the SSC theory.

The X to γ -ray spectral index $\alpha_{x\gamma} = -\log(F_\gamma/F_x)/\log(\nu_\gamma/\nu_x)$ was computed, where F_x is the energy flux at 1 keV derived from the data and F_γ is the energy flux at 1 GeV derived from the EGRET observations (Kurfess 1994). The obtained values are in the range $\alpha_{x\gamma} \sim 0.8 \div 0.9$ depending on the considered X-ray or

γ -ray states. We note that both spectral indices for the hard X-ray power law component ($\alpha_x = 1.25^{+0.40}_{-1.00}$) and the γ -ray power law ($\alpha_\gamma = 0.8^{+0.2}_{-0.2}$) are, within the errors, consistent with $\alpha_{x\gamma}$. Fig. 5 shows the multifrequency energy distribution of BL Lac 0716+714 with the hard spectral behaviour emphasized. It is tempting to speculate that the X to γ -ray spectrum of 0716+714 can be represented by a single power law of spectral index $\simeq 0.8 \div 0.9$, suggesting that both the ROSAT hard component and the γ -ray emission could originate from the same mechanism, i.e. inverse Compton scattering off relativistic electrons.

5 Conclusions

The main results of our paper can be summarized as follows:

- 1) 0716+714 displays rapid variability at X-ray wavelengths, more specifically a variation of a factor of about 7 in a time scale of two days, a doubling time scale of ~ 7000 s and a $\sim 70\%$ increase in ~ 1000 s are observed.
- 2) The strong γ -ray luminosity coupled with the rapid X-ray variability has been used to derive a lower limit of $\delta > 3.2$ for the Doppler factor.
- 3) The source clearly shows a steepening of the soft ($E \lesssim 0.9$ keV) X-ray spectrum with decreasing flux while the hard part of the spectrum remains constant.
- 4) The “low state” spectrum of 0716+714 cannot be satisfactorily fitted with a single absorbed power law model. A double power law model, representing a steep synchrotron component at low energies and a flat inverse Compton component dominating above ~ 1 keV, can describe both high and low state.

The planned multifrequency campaign with frequency coverage also at hard X-rays with the ASCA satellite (Fujimoto 1994) will undoubtedly help to put stronger constraints on the spectral shape of both components.

6 Acknowledgements

The authors wish to thank A. Celotti and G. Ghisellini for many enlightening discussions on blazar emission models and for a critical reading of the manuscript. M.C. and A.C. thank Prof. Joachim Trümper for the hospitality at MPE and G. Zamorani for helpful discussions. S.M. acknowledges financial support from MPE and ESO. This work was made possible by the financial support from the European Community, under the EEC contract No. ERB-CHRX-CT92-0033, MURST and ASI.

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FIGURE CAPTIONS

Fig. 1 ROSAT X-ray light curve of 0716+714 in the 0.1-2.4 keV energy range.

- a) Full light curve showing the whole observation.
- b) Blow-up of the “flare”.
- c) Blow-up of a rapid flux decay.

Fig. 2 Hardness Ratios (see text for definitions) calculated along the light curve of 0716+714.

- a) The source is harder during the first two periods than during the last two.
- b) Hardness ratios calculated for the high and low states of the source for the soft part of the spectrum.
- c) The same as in b) but for the hard part of the spectrum.

Fig. 3 Absorption column density and photon index 68%, 90% and 99% confidence contour levels for both high and low states (solid lines). Dashed lines represent the confidence contours for the low period, to be compared with the high state of equivalent statistic. The vertical line indicates the Galactic hydrogen column density ($N_H = 3.95 \times 10^{20} \text{ cm}^{-2}$)

Fig. 4 ROSAT spectrum of 0716+714 in the low state (upper panel). The data are fitted with a double power law model (Table 3). The residuals, in the form of the ratio data/model, are shown in the lower panel.

Fig. 5 Multifrequency energy distribution for 0716+714. Radio, microwave and infrared points are from Kühr et al. (1981), Stickel et al. (1991) and Impey & Neugebauer (1988) respectively. Optical data are referred to an average value from Stickel et al. (1993) and Biermann et al. (1981). The ultraviolet data are from IUE (Pian & Treves 1993). The X-ray data are from ROSAT (present work). The soft and hard component slopes are referred to the low state (see text). The γ -ray data are from CGRO-EGRET (Kurfess 1994).